VIRGINIA DIVISION OF MINERAL RESOURCES PUBLICATION 38

A VEIN-TYPE URANIUM ENVIRONMENT IN THE PRECAMBRIAN LOVINGSTON FORMATION, CENTRAL VIRGINIA

Thomas A. Baillieul
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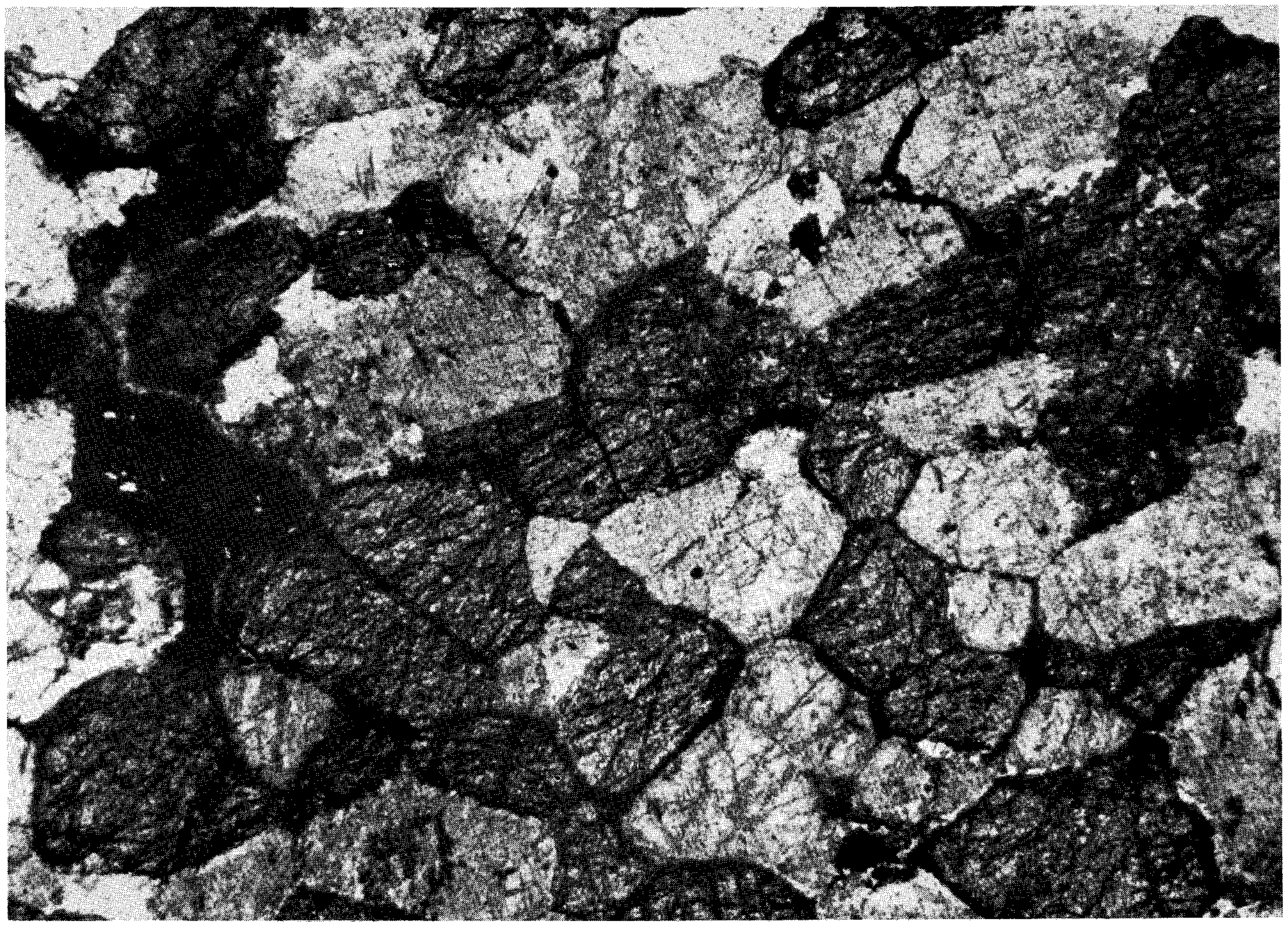

COMMONWEALTH OF VIRGINIA

DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES

Robert C. Milici, Commissioner of Mineral Resources and State Geologist

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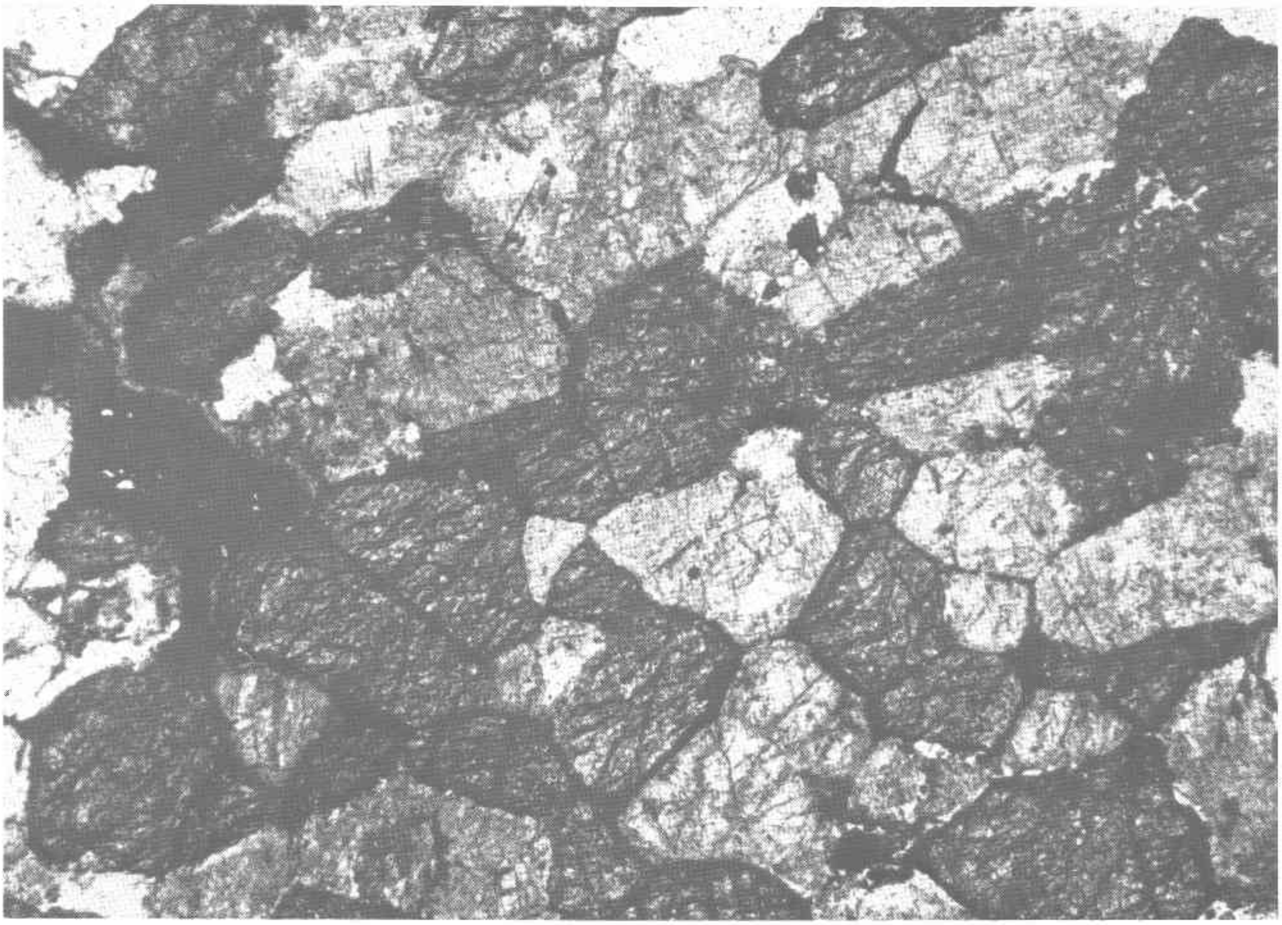

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FRONT COVER: Photomicrograph of sample MLB-262, in monazite-apatite rock from the Lovingston Formation. The rock consists of 40% monazite (dark color) and 49% apatite (lighter color) with minor quartz, opaques, and clay. Note twinned monazite. Magnification 40X, crossed-polarization with gypsum ¼ wave length plate to enhance the apatite.

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Richmond, 1982

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A VEIN-TYPE URANIUM ENVIRONMENT IN THE PRECAMBRIAN LOVINGSTON FORMATION, CENTRAL VIRGINIA[1]

By
Thomas A. Baillieul
Paul L. Daddazio

ABSTRACT

The Precambrian Lovingston Formation within the Charlottesville 1° × 2° quadrangle of north-central Virginia contains an environment favorable for vein-type uranium deposits. Anomalous radioactivity is associated closely with major zones of cataclasis in the metasedimentary Lovingston gneiss and, to a lesser extent, with lenses of granitic rock contained in the Lovingston. Within the cataclastic zones, biotite-chlorite schist layers show the largest radioelement concentrations. Thorium is the dominant radioelement and monazite, uranothorite and thorogummite are the most common radioactive minerals. Chemical assays indicate up to 4,800 ppm uranium and up to 50,000 ppm thorium for samples of weathered rock and saprolite. Elements associated with relatively high radioactivity in the area include: lanthanum, niobium, phosphorus, scandium, tin, titanium, tungsten, vanadium, yttrium, and zinc. The radioactive occurrences may be the result of hydrothermal activity following late-stage magmatic differentiation of Grenville age granitic rocks. High thorium-to-uranium ratios suggest that uranium has been removed from the system and may be concentrated at depth below the saprolite zone.

INTRODUCTION

A study of the uranium resource potential of the Blue Ridge and Piedmont provinces of the Charlottesville 1° × 2° quadrangle (Figure 1) was undertaken by Bendix Field Engineering Corporation as part of the Department of Energy's National Uranium Resource Evaluation (NURE) under contract DE-AC-13-76-GJO-1664.

Carborne scintillometer reconnaissance traverses and follow-up studies of aerial radiometric surveys (LKB Resources, 1975-1980, and Texas Instruments, 1980) revealed seven previously unknown uranium occurrences within the Precambrian Lovingston Formation. Numerous smaller radiometric anomalies were also delineated.

Ground evaluation was carried out primarily with the aid of a hand-held scintillometer (Mt. Sopris SC-132). A strip-chart recorder was coupled to the scintillometer for road reconnaissance to provide a visual record of each traverse. Field estimates of radioelement abundances were made at selected sites using a four channel gamma-ray spectrometer (Scintrex GAD-6). Several drilled wells were logged (gross gamma count) using a Mt. Sopris 1000-C instrument. Rock and soil samples were analysed by gamma-ray spectrometry for equivalent potassium (%), equivalent uranium (ppm), and equivalent thorium (ppm) content; by fluorimetry (a "wet chemistry" technique) for chemical uranium (reported as ppm U_3O_8); and by emission spectrometry for 13 additional elements. An "equivalent" assay measures the abundance of potassium, uranium, and thorium relative to their gamma-ray spectral emissions. The accuracy of this measure is affected by differing ratios of the three radioelements and the abundance of radioactive daughter products. Groundwater samples were examined in the field for radon gas content using a TSA-RE350 radon emanometer, and for Eh and pH using an Orion Research 407 A/F specific ion meter. Uranium content of groundwater was determined with Scintrex UA-3 instrument. Samples are labeled with the code letters "MLB" and a number.

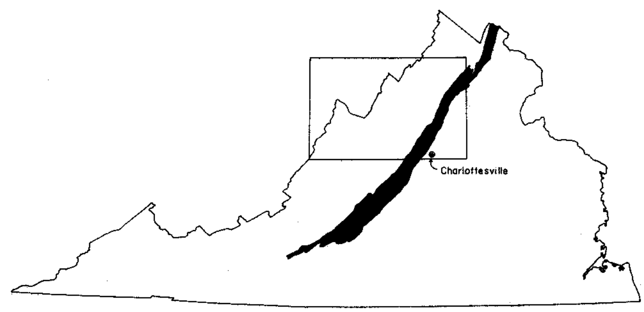

Figure 1. Distribution of the Lovingston Formation and equivalents (shaded), and outline of the Charlottesville 1° × 2° quadrangle.

GEOLOGY

The Lovingston Formation is the oldest lithologic unit in the Blue Ridge and Piedmont provinces of Virginia. It forms the core of the Blue Ridge anticlinorium. The anticlinorium includes rocks of the Blue Ridge and westernmost Piedmont provinces. Rocks of the anticlinorium are overturned to the northwest and generally dip southeast (Conley,

[1]Prepared while the authors were employed by Bendix Field Engineering Corporation for the U.S. Department of Energy, Grand Junction Office, under contract DE-AC-13-76-GJO-1664.

1978). Lithologies in the Lovingston Formation include porphyroblastic and augen gneisses, and banded biotite-feldspar gneisses which have been derived from a series of pre-Grenville sedimentary rocks (Conley, 1978). The major minerals are plagioclase, oligoclase, quartz, and biotite. Minor constituents are hornblende, chlorite, and leucoxene. Accessories include apatite, sphene, and zircon, along with ilmenite and other opaques. Almandine garnet is present along some shear zones. Feldspar in the Lovingston is commonly altered to sericite and epidote. Layers of feldspar, quartz, and feldspar augen are separated by stringers and films of biotite.

Davis (1974) dated two distinct populations of zircon from the augen gneiss. An age of 1,870 m.y. was considered to reflect the age of the original sediment

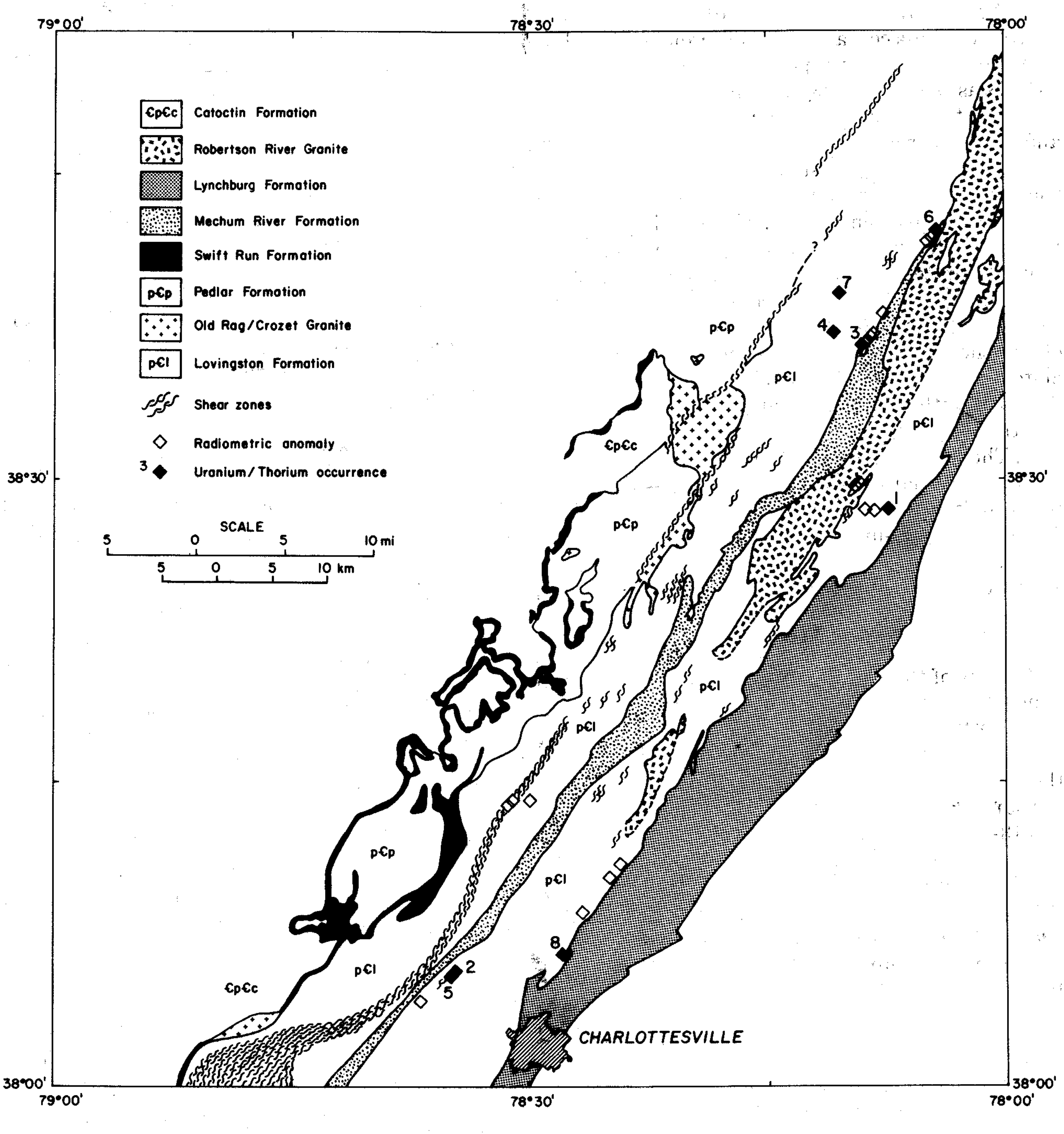

Figure 2. Detail of the Lovingston Formation in the Charlottesville quadrangle, with locations of mapped shear zones, uranium/thorium occurrences, and radiometric anomalies.

source; a second age of 913 m.y. was considered to represent the Grenville orogenic event. The Lovingston Formation gneisses contain lenses of granitic rocks which may represent intrusions or anatexis. U-Pb age dates on quartz monzonite and pegmatite zones yield dates of 1,080-1,330 m.y., and 1,080-1,180 m.y., respectively (Davis, 1974). Some of these intrusive bodies belong to the Old Rag granite, according to Allen (1963). They are texturally, mineralogically, and chemically similar to the Old Rag.

Shear zones are common throughout the Lovingston Formation; rocks in the areas of most intense shearing (Figure 2) are characterized by schistose layers produced as a result of the shearing event(s). Johnson and Gathright (1978) report a major zone of cataclastic gneiss, schist, and phyllonite along the eastern edge of the Blue Ridge province. This cataclastic zone in the area of a southeasterly dipping thrust fault separates rocks of the Lovingston Formation to the east from rocks of the Pedlar, Swift Run, and Catoctin formations to the west.

Rocks labelled Lovingston Formation in Figure 2 in the northeastern part of the area have not been mapped. However, biotite-rich, banded and augen gneisses probably equivalent to the Lovingston have been mapped there as basement units (Lukert and Halladay, 1980). Zircons from a granitic body intrusive into the augen gneiss in this region have been dated at 1,081 m.y. On the basis of age and compositional similarity of the augen, porphyroblastic, and banded gneisses in the northeastern part of the quadrangle to typical Lovingston, these rocks are considered to be Lovingston in this report.

Subsurface structure of the unit is not known. The Mechum River Formation, which forms an inlier within the Lovingston Formation, is presumed to be less than 1500 m thick. In the western part of the area, the Lovingston is separated from younger Precambrian rocks of the Blue Ridge by a complexly faulted and sheared zone (Thomas Gathright, Virginia Division of Mineral Resources, personal communication). To the east the Lovingston is in unconformable contact with the younger Lynchburg Formation.

URANIUM OCCURRENCES IN THE LOVINGSTON FORMATION

Seven previously unreported uranium occurrences and numerous areas of anomalous radioactivity were identified in the Lovingston Formation (Figure 2). All of the anomalous sites are associated with shear zones. Surface radioactivity is related primarily to the presence of thorium, although uranium in excess of 100 ppm occurs in some areas of

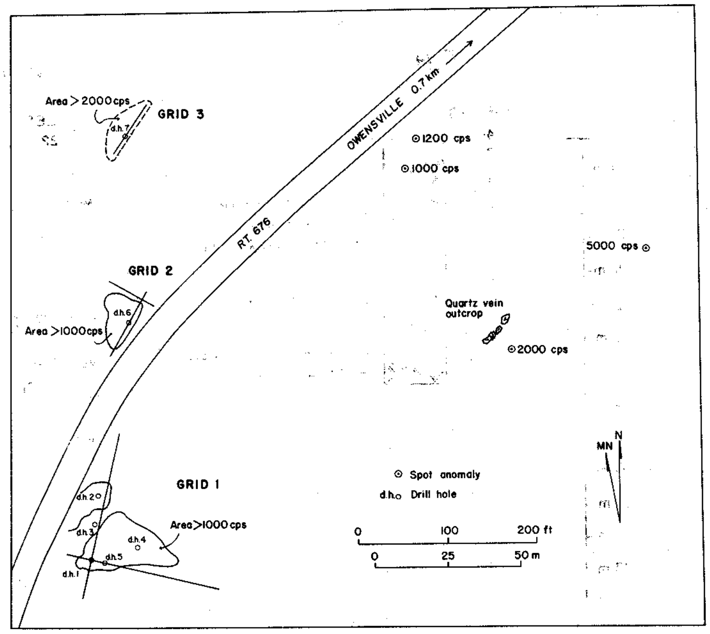

Figure 3. Detail of Occurrence 2.

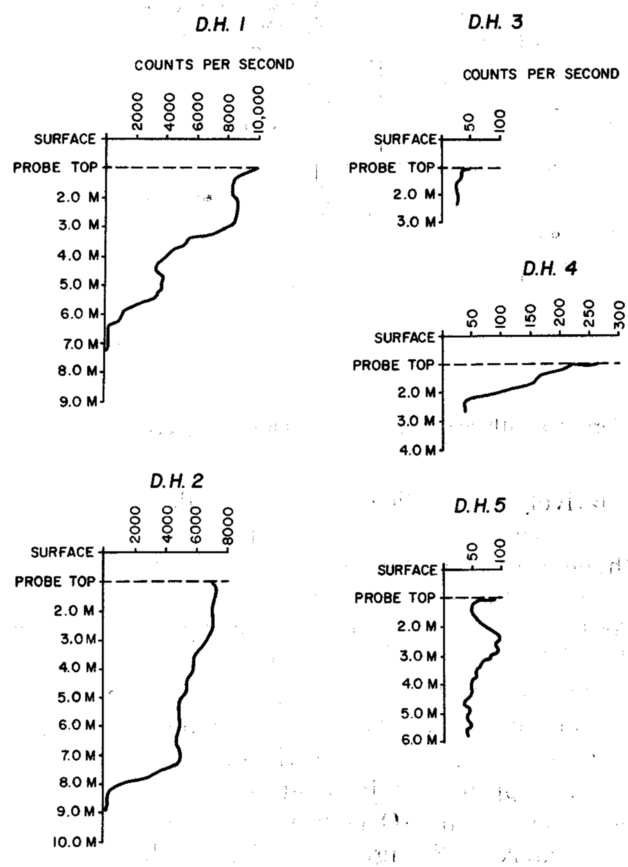

Figure 4. Gamma-ray logs (gross count) of drill holes from Occurrence 2.

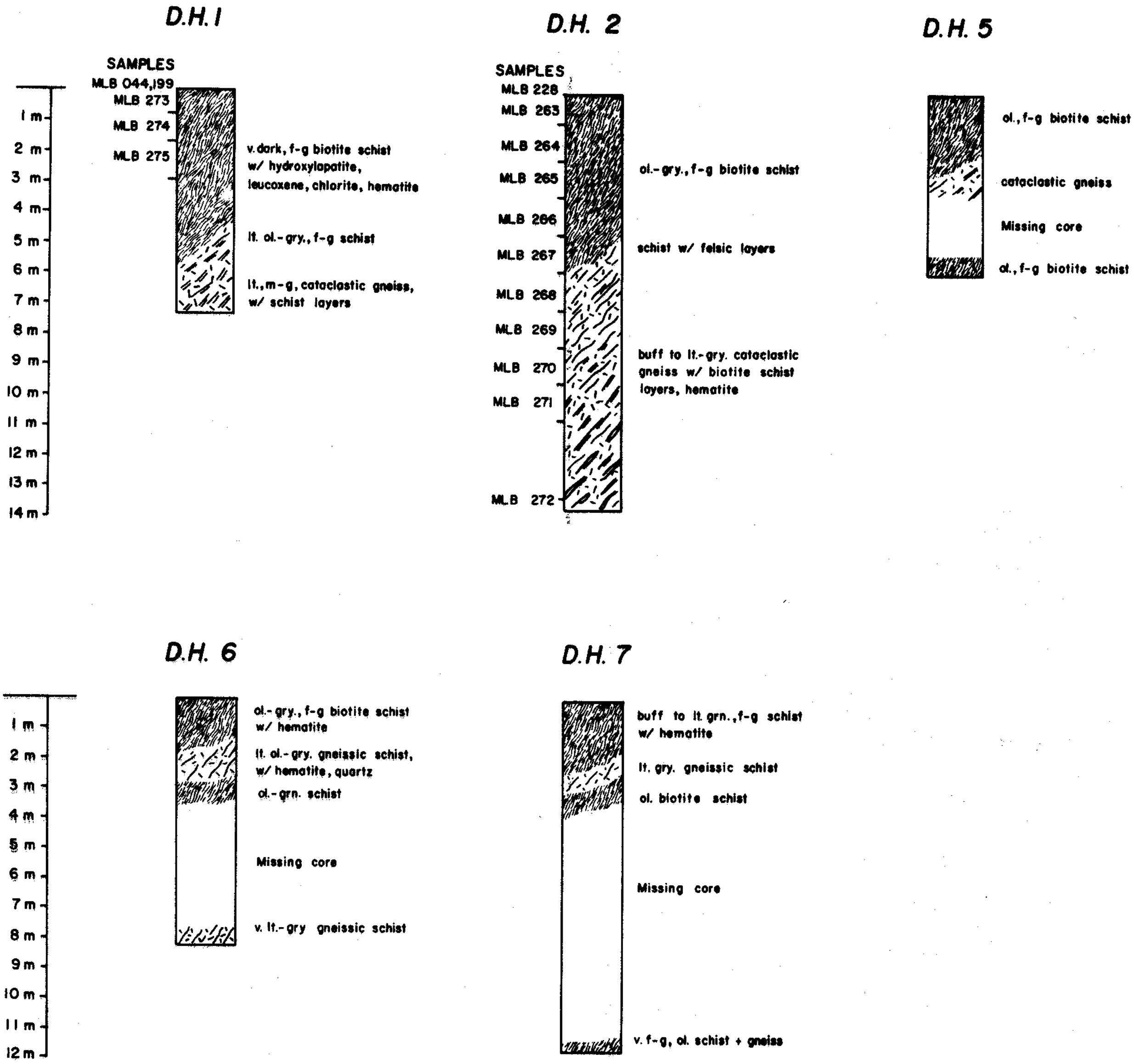

Figure 5. Lithologic logs of drill holes from Occurrence 2.

relatively high radioactivity. Anomalous rocks were considered to be those with radioactivity in excess of three times background. Background for the Lovingston Formation was measured as 100 to 200 cps (counts per second). Uranium occurrences were defined by having maximum surface radioactivity in excess of 10 times background and a surface extent measured in tens of square meters.

Two of the most significant occurrences are located approximately 6 miles (10 km) northwest of Charlottesville (Occurrences 2 and 5, Figure 2). At Occurrence 2 (Figure 3), extremely high levels of radioactivity are found in soil and saprolite; the Lovingston Formation does not crop out in this area. Gamma-ray measurements reveal a spotty pattern of radioactivity, which is closely related in places to surface drainage patterns. Scintillometer readings in this area in excess of 1,000 cps are common at the surface; counts increase in places to 20,000 cps just below the surface. A few samples from pits and core drilling revealed biotite-chlorite schist within a cataclastic gneiss to be the primary host of the radioactivity. Chemical analyses (sample numbers 044 and 199, Table 1a) show 530 and 278 ppm U_3O_8, respectively. Laboratory gamma-ray analyses show 330 to 583 ppm equivalent uranium (eU) and 10,500 to 11,000 ppm equivalent thorium (eTh), respectively, for the same samples. Field gamma-ray assays were attempted at the site of these two samples; however, inaccurate results were obtained as the spectrometer was not calibrated for such high thorium levels.

Unmineralized Lovingston gneiss at Occurrence 2 contains only 6 ppm U_3O_8 and 22 ppm eTh (sample no. 045). Increases in abundances of radioactive elements are accompanied by increases in levels of lanthanum, phosphorus, titanium, tungsten and yttrium (Table 1a and 1b). One soil sample was found to have an elevated level of gold.

Gamma-ray and lithologic logs of drill holes (Figure 4 and 5) indicate an uneven distribution of radioelements in the Occurrence 2 area. Whereas all seven drill holes showed high levels of radioactivity in the upper meter of saprolite, only two holes (1 and 2) gave an indication of radioactivity at depth. Hole 1 showed high radioactivity to a depth of 20 feet (6 m) and hole 2 showed high radioactivity to a depth of 26 feet (8 m). Chemical and laboratory gamma-ray assays of core from hole 2 show fluctuations in radioelement concentrations with depth (Figure 6). The similarity of the U_3O_8 and eU curves shows that uranium is in radiometric equilibrium with its daughter products everywhere except in the uppermost zone, where some uranium has been oxidized and leached. Because of the relatively high concentrations of uranium and because the similarity of the eU and eTh curves, it is probable that the uranium is associated with thorium in mineral species that are chemically resistant.

The host rock at Occurrence 2 (sample no. 045) is a biotite-feldspar-quartz mylonitic gneiss. Quartz composes 21 percent of the rock, plagioclase 28 percent, K-feldspar 11 percent, and biotite 30 percent.

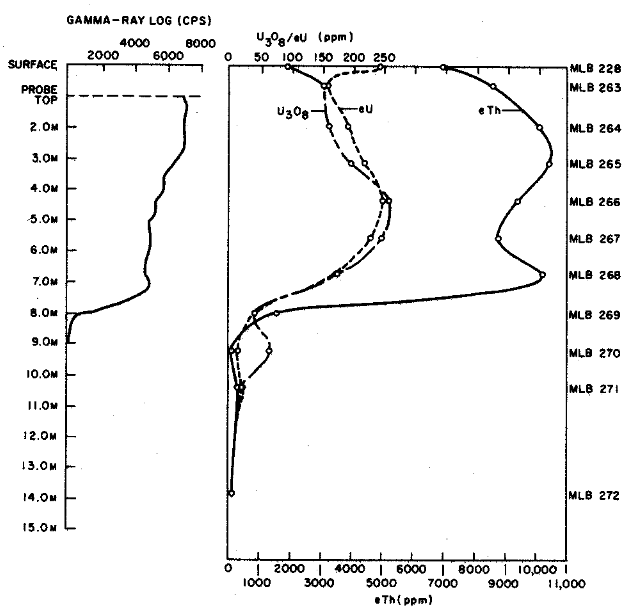

Figure 6. Comparison of chemical and gamma-ray assay results for drill hole no. 2, Occurrence 2.

Sphene, garnet, apatite, zircon, and epidote make up minor to trace amounts of the rock. Texturally, the rock consists of feldspar and garnet porphyroclasts (augen) in a mortar of quartz and biotite. A flow texture commonly is well developed. In the immediate vicinity of the radioactive anomalies the gneiss is a highly altered quartz diorite protomylonite (sample no. MLB 272 from drill hole 2). Iron oxides, epidote, and biotite occur in place of plagioclase and constitute much of the cataclastic mortar. The biotite schist (sample nos. MLB 044 and MLB 275) is variable in composition. Rutilated biotite comprises 60 to 75 percent of the rock, hydroxylapatite about 15 percent, quartz 2 to 4 percent, leucoxene/ilmenite/sphene 5 percent, and chlorite up to 5 percent. Thorium-enriched clay makes up 2 to 3 percent of the rock, and zircon, monazite, garnet, muscovite and limonite occur in trace amounts. A thorium phosphate is found as inclusions in the biotite and as rims on the apatite. The color of the biotite schist varies from black to pale olive; the lighter color results from bleaching of the biotite and an increase in the abundance of muscovite (10 percent or greater).

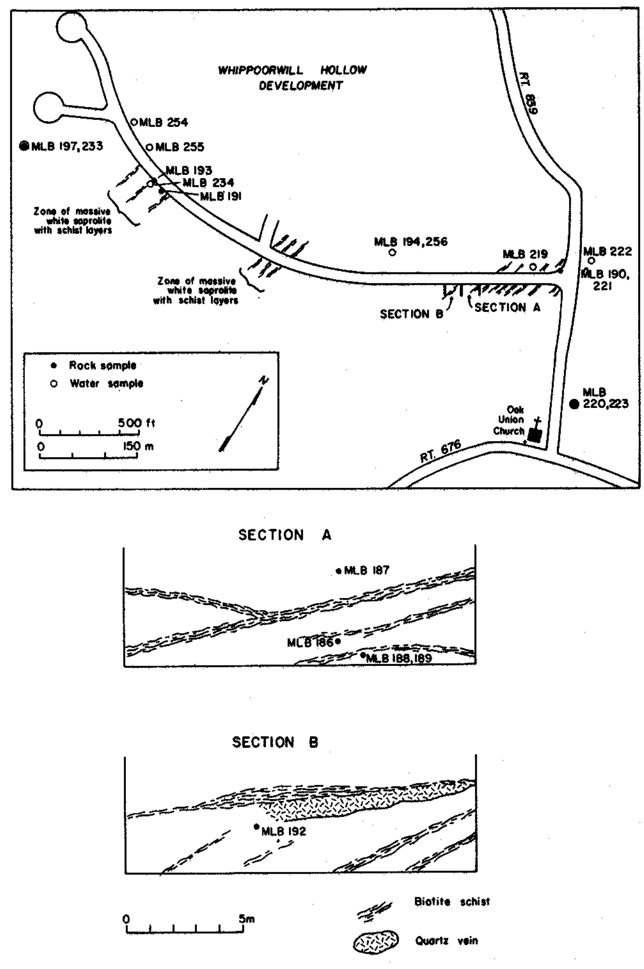

Figure 7. Detail of Occurrence 5.

Table 1a. Selected trace element analyses for rocks from the Lovingston Formation*

SAMPLE NO.	OCCURRENCE NO.	U308	eU	eTh (cTh)	Co	La	Mo	Nb	Ni	P	Sc	Sn	Ti	V	W	Y	Zn
010	6	8		(80)	-10	-10	-10	-100	-50	-100	-3	-10	1130	160	-100	105	-100
011	3	1310		(13,800)	24	7980	31	1100	-50	13,000	92	36	23,400	794	5020	1217	343
012	3	22		(475)	-10	959	29	-100	-50	23,300	23	40	19,500	651	395	961	190
014	3	4880		(52,000)	87	+20,000	127	7000	163	1250	363	159	72,200	1860	+10,000	1681	1130
015	6	35		(533)	-10	184	-10	-100	-50	667	-3	-10	2760	208	-100	78	-100
016	3	3300		(51,500)	116	+20,000	212	8890	201	1530	1130	215	110,000	2290	+10,000	1687	1620
017	3	2310		(11,400)	77	+20,000	224	+100,000	193	-100	202	420	83,200	2220	+10,000	4740	1520
033	1	3	3	30	-10	-10	-10	-100	-40	1270	-3	-10	334	n.d.	-100	52	-100
034	1	2	2	8	-10	-10	-10	-100	-40	304	-3	-10	1550	n.d.	-100	30	-100
044	2	530	332	11,425	55	1270	31	-100	-40	35,700	50	29	17,000	n.d.	718	673	147
045	2	6	2	22	28	126	32	-100	-40	5400	48	28	10,800	n.d.	-100	79	-100
186	5	8	10	258	-10	26	-10	-100	-40	-100	-3	-10	3220	n.d.	-100	31	-100
187	5	-1	3	28	-10	-10	-10	-100	-40	-100	-3	-10	2920	n.d.	-100	15	-100
188	5	11	16	498	-10	28	17	-100	-40	-100	-3	19	4220	n.d.	-100	39	-100
189	5	3	3	3	36	12	40	-100	47	-100	16	71	10,600	n.d.	-100	48	338
191	5	4	3	33	-10	35	-10	-100	-40	-100	-3	-10	1210	n.d.	-100	44	-100
192	5	5	6	114	-10	-10	11	-100	-40	-100	-3	-10	3200	n.d.	-100	22	-100
193	5	69	66	311	-10	150	-10	-100	-40	-100	-3	-10	1830	n.d.	-100	561	-100
194	5	3	3	16	-10	-10	16	-100	-40	-100	-3	-10	4560	n.d.	-100	20	-100
199	2	278	583	10,563	-10	546	37	-100	-40	10,900	17	52	9900	n.d.	365	416	214
200	2	24	33	1080	-10	80	13	-100	-40	-100	-3	-10	4840	n.d.	-100	45	-100
205	3	167	169	2873	-10	2770	28	-100	48	8640	20	-10	5380	n.d.	2560	440	-100
206	3	11	10	20	22	75	30	-100	40	3820	20	20	9220	n.d.	-100	50	-100
207	4	48	61	374	82	506	65	-100	48	25,400	82	98	38,100	n.d.	968	324	340
208	4	3	1	4	-10	52	18	-100	-40	2380	7	-10	6390	n.d.	-100	35	-100
209	4	3	1	5	-10	44	14	-100	-40	2120	-3	-10	5150	n.d.	-100	35	-100
210	7	32	35	667	-10	468	18	-100	-40	3420	-3	-10	11,200	n.d.	-100	75	-100
212	3	20	19	68	-10	-10	16	-100	-40	-100	-3	-10	1680	n.d.	-100	-10	-100
213	3	74	62	528	-10	74	23	-100	-40	220	-3	-10	3990	n.d.	-100	45	-100
221	5	139			-10	-10	17	-100	-40	-100	-3	-10	4920	n.d.	-100	26	-100
223	5	4	1	2	-10	-10	15	-100	-40	-100	-3	-10	4560	n.d.	-100	28	-100
228	2	91	241	6861	-10	259	22	-100	-40	1430	-3	19	6410	n.d.	-100	123	128
257	6	27	17	151	-10	-10	-10	-100	-40	-100	-3	-10	1180	n.d.	-100	20	-100
258	6	76	79	624	-10	225	25	-100	-40	1830	-3	-10	5860	n.d.	326	67	-100
259	6	58	56	1108	-10	85	47	-100	-40	2090	17	51	8360	n.d.	448	37	299
260	6	21	23	169	-10	-10	-10	-100	-40	150	-3	-10	1730	n.d.	-100	-10	-100
261	7	44	53	1268	-10	370	14	-100	-40	2880	-3	-10	7980	n.d.	-100	40	-100
262	7	138	619	31,300	64	+20,000	188	6410	41	+100,000	124	145	22,800	n.d.	+10,000	6460	613
263	2	150	156	8500	28	365	34	-100	-40	12,000	10	40	8850	n.d.	475	327	113
264	2	159	189	10,000	-10	259	30	-100	-40	17,500	-3	28	8450	n.d.	578	227	113
265	2	195	215	10,300	-10	318	27	-100	-40	18,800	5	28	10,300	n.d.	404	244	-100
266	2	257	248	9300	26	428	33	-100	-40	21,200	18	33	12,400	n.d.	465	286	130
267	2	248	228	8710	-10	358	26	-100	-40	17,900	9	21	10,400	n.d.	547	226	-100
268	2	172	171	10,100	-10	379	22	-100	-40	29,300	6	13	9150	n.d.	610	244	-100
269	2	40	39	1560	-10	106	-10	-100	-40	7170	-3	-10	2950	n.d.	-100	81	-100
270	2	64	15	96	-10	84	18	-100	-40	7700	8	-10	2760	n.d.	-100	89	-100
271	2	21	20	317	-10	65	13	-100	-40	4720	-3	-10	3390	n.d.	165	72	-100
272	2	6	7	141	-10	45	24	-100	-40	10,300	10	24	3580	n.d.	246	106	-100
273	2	210	269	12,200	-10	439	35	-100	-40	12,600	-3	-10	7030	n.d.	-10-	241	-100
274	2	240	231	11,000	-10	273	32	-100	-40	13,300	-3	-10	7320	n.d.	-100	264	-100
275	2	210	208	10,200	-10	243	51	-100	-40	15,900	8	51	11,300	n.d.	350	290	279

*(all analyses reported as parts per million).
(-) indicates "less than"

Co, cobalt
La, lanthanum
Mo, molybdenum
Nb, niobium
Ni, nickel
P, phosphorus
Sc, scandium
Sn, tin
Ti, titanium
V, vanadium
W, tungsten
Y, yttrium
Zn, zinc

Table 1b. Trace element analyses of ground water samples from the Lovingston Formation at Occurrence 5.

SAMPLE NO. (MLB)	Rn (pCi/1)	U_3O_8 (ppb)	Cu (ppb)	Se (ppb)	V (ppb)	Zn (ppb)	SO_4 (ppm)	PO_4 (ppm)
046	54	0.07	4	-5	-5	-5	-1	-1
149	69	0.14	-2	-5	-5	-5	-1	1
150	218	0.10	-2	-5	-5	-5	-1	-1
197	1487	0.36						
214	709	0.28	73	-5	-5	33	3	-1
215	654	1.27	112	-5	-5	29		
219	0	0.08						
220	11	0.04	156	-5	-10	23	-1	-1
222	45	0.10						
234	1170	0.23						
254	616	0.17						
255	1315	0.08						
256	962	0.13						

(-) indicates "less than"

At Occurrence 5 (Figure 7) recent excavations for a housing development exposed a broad area of cataclastic gneiss and associated schist. Although most exposures were of highly weathered saprolite, detailed structure could be seen. Biotite schist layers have orientations both concordant and discordant with the major shear foliation. Massive, white saprolite in two bands 10 feet (3 m) to 17 feet (5 m) wide in the gneiss is presumed to represent a felsic intrusive.

At this locality the highest radioactivity and radioelement concentration is located in or near the biotite schist layers. Maximum levels of uranium in the mineralized schist at the surface range from 69 ppm to 140 ppm U_3O_8 (sample nos. 193 and 221). Gamma-ray analyses show a range of 10 to 140 ppm equivalent uranium and 13 to 3400 ppm equivalent thorium. Thorium/uranium ratios vary from 4 to 77. The sheared gneiss (sample nos. 187, 188, and 192) has lower levels of uranium and thorium on the average than do the schist layers: 1 to 11 ppm U_3O_8, 3 to 16 ppm equivalent uranium, and 28 to 498 ppm equivalent thorium. The white felsic saprolite (sample no. 191) contains 4 ppm U_3O_8, 3 ppm equivalent uranium and 33 ppm equivalent thorium. Logs of water wells and analyses of radon gas and uranium in groundwater at Occurrence 5 indicate zones of mineralization at depths of up to 131 feet (40 m).

At Occurrence 5, few elements show a strong positive correlation with radioelement abundance (Table 1a). Lanthanum, manganese, yttrium, and zinc show enrichment in some zones where concentrations of radioelements are two to ten times the levels found in unmineralized rock. Sample no. MLB 189, a dark, hematite-stained biotite schist, shows greatly elevated levels of magnesium.

No microscopic examination was made of the very friable saprolite at this location; however, one quartz-rich sample of pale-olive schist (sample no. MLB 190) was sufficiently indurated for thin-section analysis. This rock contains 58 percent biotite (bleached), 10 percent muscovite, 20 percent quartz, 7 percent limonite (as stringers throughout), and minor amounts of chlorite and leucoxene. The quartz is granulated and segregated into veinlets or stringers.

A red alteration color associated with some of the schistose layers is much more intense than in the surrounding saprolite, suggesting hematitization along some of the shears. Other evidences of alteration are masked by extreme weathering.

Immediately north of the South Fork Rivanna River Dam (Occurrence 8, Figure 2) a large quarry exposes anomalously radioactive granites and schists of the Lovingston Formation (sample nos., MLB, 216, 217, 218). A highly weathered biotite-muscovite-plagioclase-quartz schist near the quarry contains isolated radiometric highs of two to four times background. Within the quarry, there is granitic rock classified as a quartzo-feldspathic protomylonite (sample no. MLB 216) containing leucocratic veins. Shear-formed fractures are abundant along the quarry face. Table 2 shows the variation of uranium and thorium in rocks from the quarry.

Table 2. Radioactivity of rocks from quarry in Occurrence 8 area.

Sample No. (MLB)		ppm U_3O_8	ppm eU	ppm eTh	Th/U
216	Fractured leucocratic dike rock	22	22	56	2.6
217	Non-fractured granite	15	7	56	8.0
218	Non-fractured granite	12	11	47	4.3

Immediately north of the quarry, near the Albemarle County Airport, Stow (1955) reported radioactive schist and gneiss with radiometric readings of 40 times background. The only trace of the occurrence which could be found during this field study was a boulder of granitic gneiss about 3 feet (1 m) in diameter which gave anomalous radiometric readings up to 10 times background. Gamma-ray assays show 42 to 142 ppm equivalent uranium and 43 to 83 ppm equivalent thorium for this boulder. Low thorium/uranium ratios for the rock (0.6 to 1.0) are unusual in an otherwise high-thorium terrain.

Farther north, the Lovingston Formation contains several uranium occurrences in the vicinity of Bessie Bell Mountain (Figure 8). In this area there are medium- to coarse-grained granite bodies, and pegmatite float is common. Here, as elsewhere in the quadrangle, the highest levels of radioactivity are in cataclastic rocks. Sheared phyllites and schists contain 7 to 55 ppm equivalent uranium and 30 to 400 ppm equivalent thorium (gamma-ray field assays). Quartz-feldspar microbreccias and protomylonites contain 50 to 150 ppm equivalent uranium and 100 to 1,200 ppm equivalent thorium. Metamict pegmatitic breccias (sample nos., MLB, 011, 014, 016, and 017) have uranium levels of 1,000 to 4,800 ppm U_3O_8. Elevated levels of radioelements in the Bessie Bell Mountain region show correlations with increased abundances of cobalt, lanthanum, niobium, titanium, tungsten, vanadium, and zinc (Table 1a). Petrographic studies show that pyrite is almost always present in these highly radioactive rocks.

The major radioactive minerals in the Lovingston Formation are monazite, uranothorite, and thorogummite. Monazite occurs both as primary grains and secondary fracture-fillings. One sample (MLB 262) from Occurrence 7 consists of 40 percent monazite and 49 percent apatite of secondary, vein-filling origin. Uranothorite occurs as bladed inclusions in monazite and in biotite in several areas. Thorogummite was identified in augen gneiss samples from the Bessie Bell Mountain area (Halladay, 1978). In most samples the abundance of radioactive minerals observed in the rock is too low to account

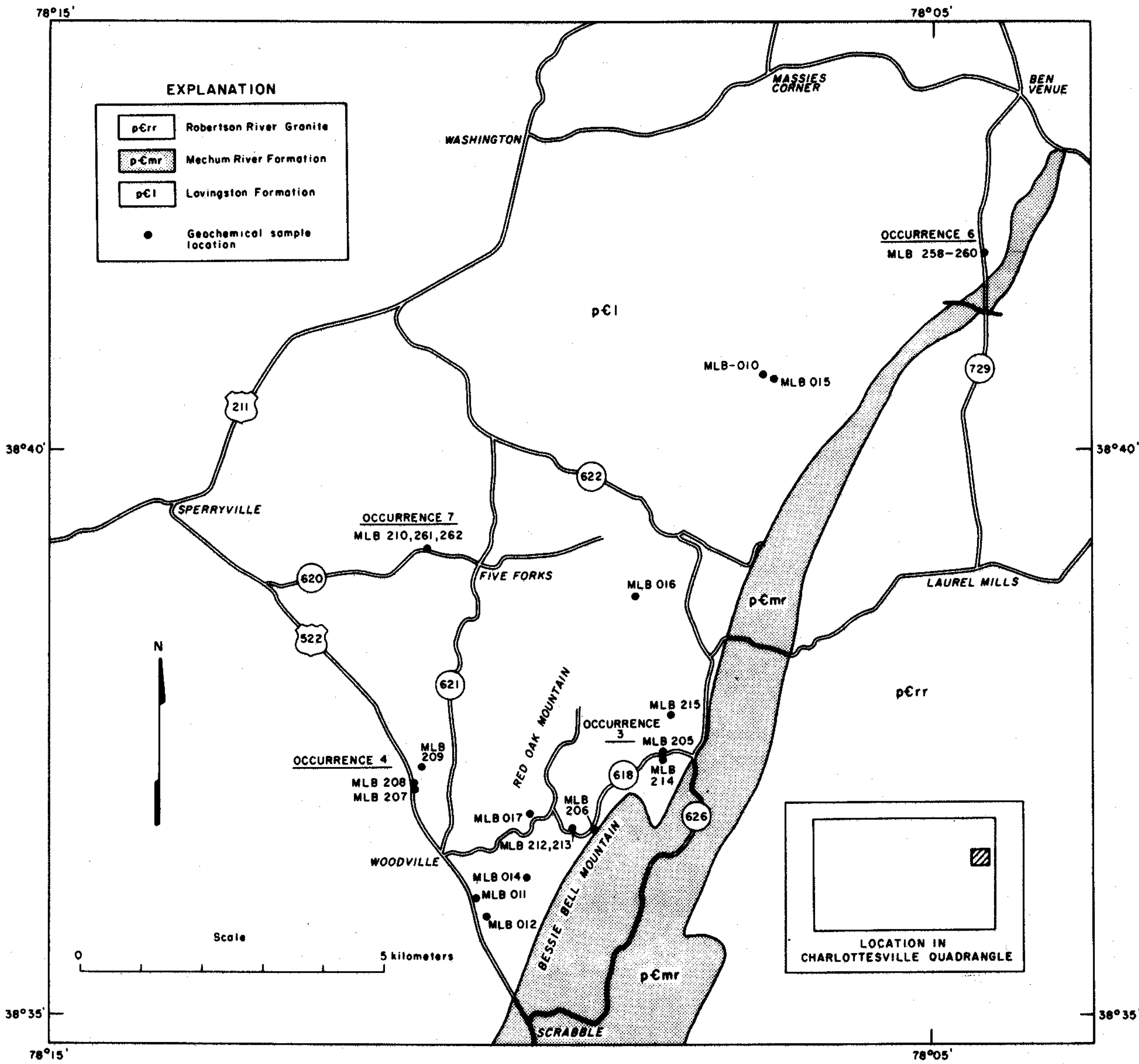

Figure 8. Uranium/thorium occurrences in the vicinity of Bessie Bell Mountain.

for the chemical levels of thorium and uranium. It is inferred that these radioelements are in finely divided mineral particles dispersed throughout the rock. The radioactive minerals do not represent remnants of ancient placer deposits in the original sedimentary sequence. Rather, they are secondary enrichments in favorable structural zones. Thorium abundance is far in excess of uranium abundance in nearly all of the samples examined. The most radioactive samples have a thorium to uranium ratio greater than 30:1 (Figure 9). The relatively higher abundance of thorium suggests that uranium has been selectively removed from the rocks.

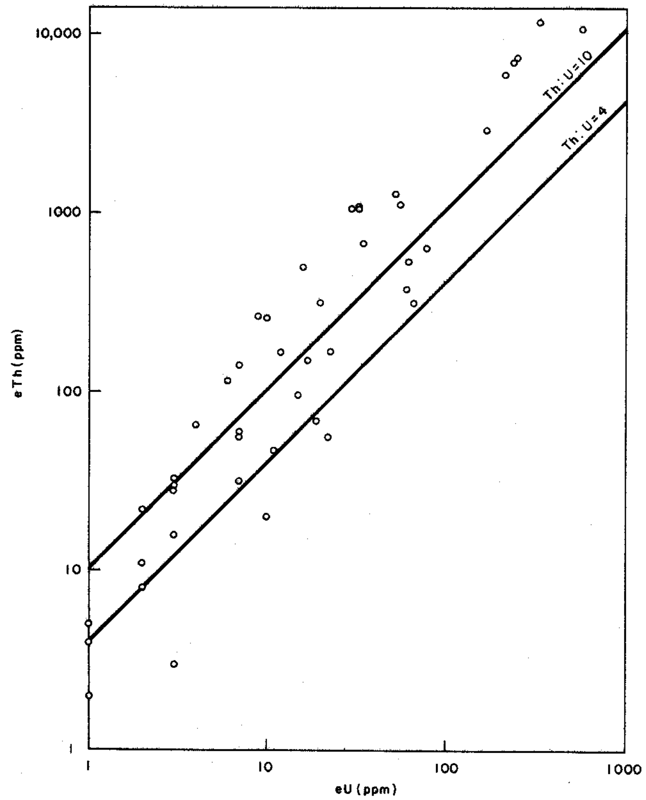

Figure 9. Plot of eU vs. eTh for rocks of the Lovingston Formation.

ORIGIN OF URANIUM/THORIUM OCCURRENCES

Much study has been given to vein-type uranium deposits in highly metamorphosed terrain and several genetic models have been developed. One theory proposes hydrothermal emplacement of uranium from late-stage magmatic differentiates and thermal remobilization of uranium within the country rock (Hegge and Rowntree, 1978; Rich and others, 1977). In a second model uranium concentration is accomplished by supergene enrichment in rocks unconformably underlying terrestrial sedimentary rocks (Dahlkamp, 1978; Hoeve and Sibbald, 1978). The high levels of thorium observed in the Lovingston Formation suggest a magmatic rather than supergene origin of the uranium occurrences (Table 2), because even though concentrations of thorium in magmatic rocks are not generally so high as observed in this study, thorium is in no case concentrated by supergene enrichment.

Rich and others (1977) describe two types of uranium occurrences in the Beaverlodge district of Saskatchewan:

(1) Syngenetic deposits in late-stage igneous rocks and in granitized sedimentary rocks—monazite, uranothorite, xenotime, uraninite, cyrtolite, pyrochlore-microlite in pegmatites, granites, and granitized rock. Not economic.
(2) Epigenetic deposits in metasediments—pitchblende in altered portions of metasediments, closely associated with fractures and shears (no thorium present).

It may be that the uranium occurrences so far identified in the Lovingston Formation are of the first type and that further exploration will reveal occurrences of the second type. Pitchblende may have been largely removed during the deep weathering of the Virginia Piedmont. Thorium minerals, which are relatively insoluble, remained near the surface.

It is postulated that there were several periods when uranium concentrations could have taken place in the Lovingston Formation.

(1) Formation of cataclastic zones in the Lovingston Formation during Grenville time (about 1000 m.y.) and coincident emplacement of the anomalously radioactive Old Rag and Crozet granites in the Lovingston. The granites contain up to 25 ppm U_3O_8, with an average of 5 to 10 ppm U_3O_8. The average thorium-to-uranium ratios for the granites is about 10:1, suggesting uranium depletion (Figure 10).
(2) Emplacement of the Robertson River granite between 700 and 600 m.y. This granite is low in uranium and thorium and was probably not a significant source of uranium. However, the heat and fluids generated by this intrusion may have caused mobilization and reconcentration of existing uranium.
(3) Extrusion of the Catoctin basalt through numerous feeder dikes in the Lovingston Formation at 600 m.y. Heat of dikes possibly caused mobilization and reconcentration of uranium.
(4) Taconic orogeny (about 430 m.y., Late Ordovician time). Deformation caused Piedmont rocks to be sheared and intruded by uranium-enriched granites. These intrusives may have provided both uranium and mobilizing fluids

for additional concentration within the Lovingston, although they are strictly east of the Charlottesville quadrangle.

(5) Acadian and Appalachian orogenies (about 350 m.y., Late Devonian, and perhaps 300 m.y. or later, Late Paleozoic). Deformation produced renewed movement on shear zones. Granites emplaced to the east of the Charlottesville quadrangle may have been sources of additional uranium and mobilizing fluids.

(6) Migration of meteoric waters may have oxidized uranium and concentrated it in rocks well below the surface.

The suggested effects of some of these events need a word of explanation. Event (1), granitic rocks, quartz monzonites and pegmatites in the Lovingston may belong to the Old Rag granite, as suggested by Allen (1963). The Old Rag has substantial radioactivity. Event (2), the Robertson River granite cuts rocks probably equivalent to the Lovingston. The intrusive body may have invaded the more typical Lovingston or heated it enough to cause migrations of uranium. Events (4 and 5), these granites have not been observed to cut the Lovingston Formation, but heat accompanying their formation may have caused migration and concentration of uranium and thorium ions in the Lovingston.

Metasedimentary rocks of the Swift Run, Lynchburg and Mechum River formations unconformably overlie the Lovingston Formation in the Charlottesville quadrangle. The stratigraphic relationships of these three formations is not known because they are nowhere in juxtaposition (see Figure 2). Dennison and Wheeler (1975) considered the Swift Run to be fluvial in origin; Conley (1978) hypothesized a fluvio-deltaic depositional environment for the Lynchburg Formation; and the Mechum River Formation has been described as a synclinal infold of Lynchburg Formation rocks into basement gneisses (Brown, 1973), and as a Triassic-like half-graben flanking the main Lynchburg depositional basin (Schwab, 1974). Gooch (1958) considers the Mechum River, Swift Run, and Lynchburg formations to be erosional remnants of a single stratigraphic unit.

These metasedimentary rocks, which are at least partly of terrestrial origin, may have provided a continuous cover for the Lovingston Formation during the Late Proterozoic. Figure 11 shows the distribution of the three units in the Charlottesville quadrangle and Figure 12 provides a generalized cross-sectional view. Each of these units has undergone dynamothermal metamorphism.

Kalliokoski and others (1978) consider these metasedimentary rocks to have some resemblance to the cover rocks found in association with uranium deposits in Saskatchewan and in the Northern Territory of Australia. A paleo-regolith in the Lovingston Formation, which is on the surface of the Lovingston just below the metasediments, represents a period of subaerial weathering. Clast types found in the metasediments reflect a deeply weathered provenance (Kalliokoski and others, 1978). It is possible that a uranium-concentrating geochemical system similar to those proposed for unconformity-related uranium deposits elsewhere was in existence in this part of Virginia during the Late Proterozoic.

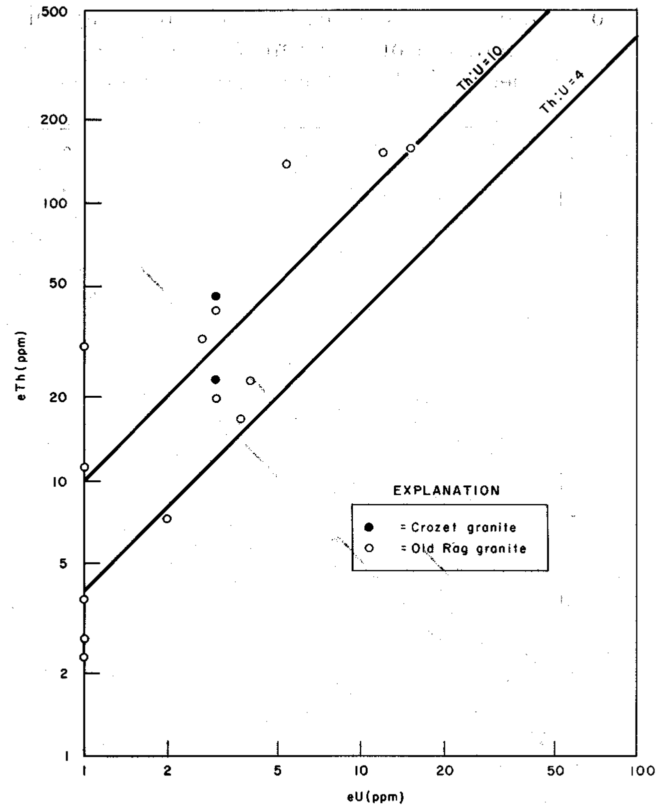

Figure 10. Plot of eU vs. eTh for samples of Crozet and Old Rag granites.

SUMMARY

The Lovingston Formation appears to contain vein-type uranium deposits in metamorphosed sedimentary rocks similar to ones described by Mathews (1978). Vein-type occurrences of uranium, thorium, and rare earth elements in major cataclastic zones in the study area indicate an origin by late-stage magmatic differentiation and hydrothermal emplacement. High thorium-to-uranium ratios suggest that uranium was removed from the system and that large, primary uranium concentrations may exist below the weathered surface. Groundwater movement along a major unconformity between the Lovingston Formation and overlying sediments may have produced secondary enrichment during Late Precambrian times.

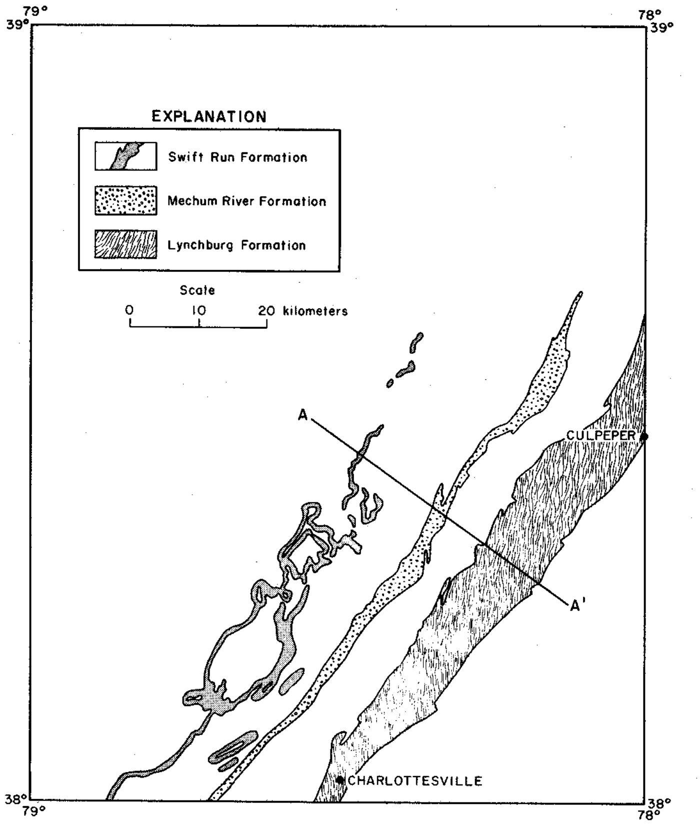

Figure 11. Distribution of Upper Precambrian metasedimentary rocks in the Charlottesville quadrangle.

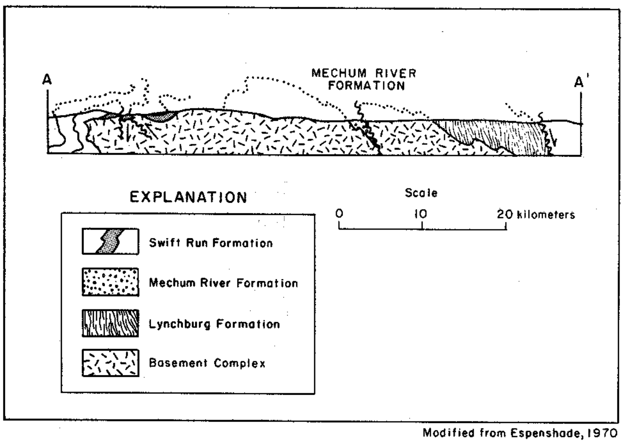

Figure 12. Generalized cross-section of Figure 11.

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